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Plant Foods and Different Uses of Grinding Tools at the Neolithic Site of Tanghu in Central China

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ABSTRACT
In the central plain of China, grinding tools are a common category of artefacts at sites attributed to the Peiligang Culture (c. 9000-7000 BP). This paper focuses on the grinding tool assemblage from the site of Tanghu, the largest Peiligang Culture settlement yet discovered. The results from the microwear and residue analyses both suggest that cereals were the primary plant material processed with the grinding tools. Other plants, including acorns and underground storage organs, were also processed, but probably to a smaller extent. Furthermore, microwear analysis suggests that the dry-grinding technique was adopted for cereal processing, and a piece of hide or animal skin was placed underneath the grinding slabs to gather the processed plant material. Apart from plant food processing, one of the grinding tools was also involved in processing bone. These data put more insights into the Neolithic culinary practices and different uses of grinding tools in this region.

KEYWORDS
Plant foods; use-wear; starch grain; Peiligang Culture; grinding tools

Introduction

Plant foods are significant resources of energy, protein, vitamins, and minerals in human diets in the present and past (Herry, 2014; Liu et al., 2013; Nestle, 1999; Wickler et al., 1992; Wollstonecroft et al., 2008). Investigating prehistoric exploitation of plant foods and plant food processing techniques enriches our understanding of their impact on human health and culinary cultures (e.g. Capparelli et al., 2011; Sadvari et al., 2015; Searcy, 2011; Yang & Jiang, 2010). Archaeological excavations to date have provided some fascinating evidence for the consumption of plant foods by past societies worldwide (e.g. Arranz-Otaegui et al., 2018; Fuller & Gonzalez Carretero, 2018). A striking example in China is Neolithic noodles unearthed at the site of Lajia (ca. 4000 BP), where the shape of the noodles could still be clearly recognized in a sealed earthenware bowl (Lu et al., 2005). However, such archaeological findings are not always encountered, probably due to complex post-depositional processes (Evershed, 2008). Thus, archaeologists often study ancient grinding tools to retrieve information on prehistoric plant foods and food processing techniques in different regions worldwide.

In the upper catchment of the Huai River (UCHR) in Central China, grinding tools (e.g. Figure 1(c and d)) were frequently unearthed from sites associated with the Neolithic Peiligang Culture (c. 9000-7000 BP), coinciding with the emergence of agriculture (Li, 1979; Liu et al., 2010; Ren et al., 1984; Yang et al., 2017; Zhang, 2015, 1999; Zhang et al., 2012; Zhang & Wang, 1998). Although intensive studies have been carried out to understand "what did these grinding tools process?", the yielded results are not always consistent. For example, at the sites that are all attributed to the Peiligang Culture: Egou, Shigu, and Peiligang, the grinding tools have been subjected to starch grain and microwear analysis (Liu et al., 2010; Zhang et al., 2011). The results suggest that these tools were primarily used for processing acorns. On the other hand, our recent study conducted at Jiahu in the same region reveals that cereals were mainly processed with the grinding tools, while some of the Jiahu grinding tools were associated with processing wood-like material (Li et al., 2018).

In order to add more data to facilitate the discussion of the use of grinding tools and their roles among the early farming communities, this paper analyzes the grinding tools unearthed from the Peiligang Culture site of Tanghu in the UCHR region (Figure 1 (a)). The site is located in the city of Xinzhen in Henan Province. It covers nearly 1.4 square kilometres

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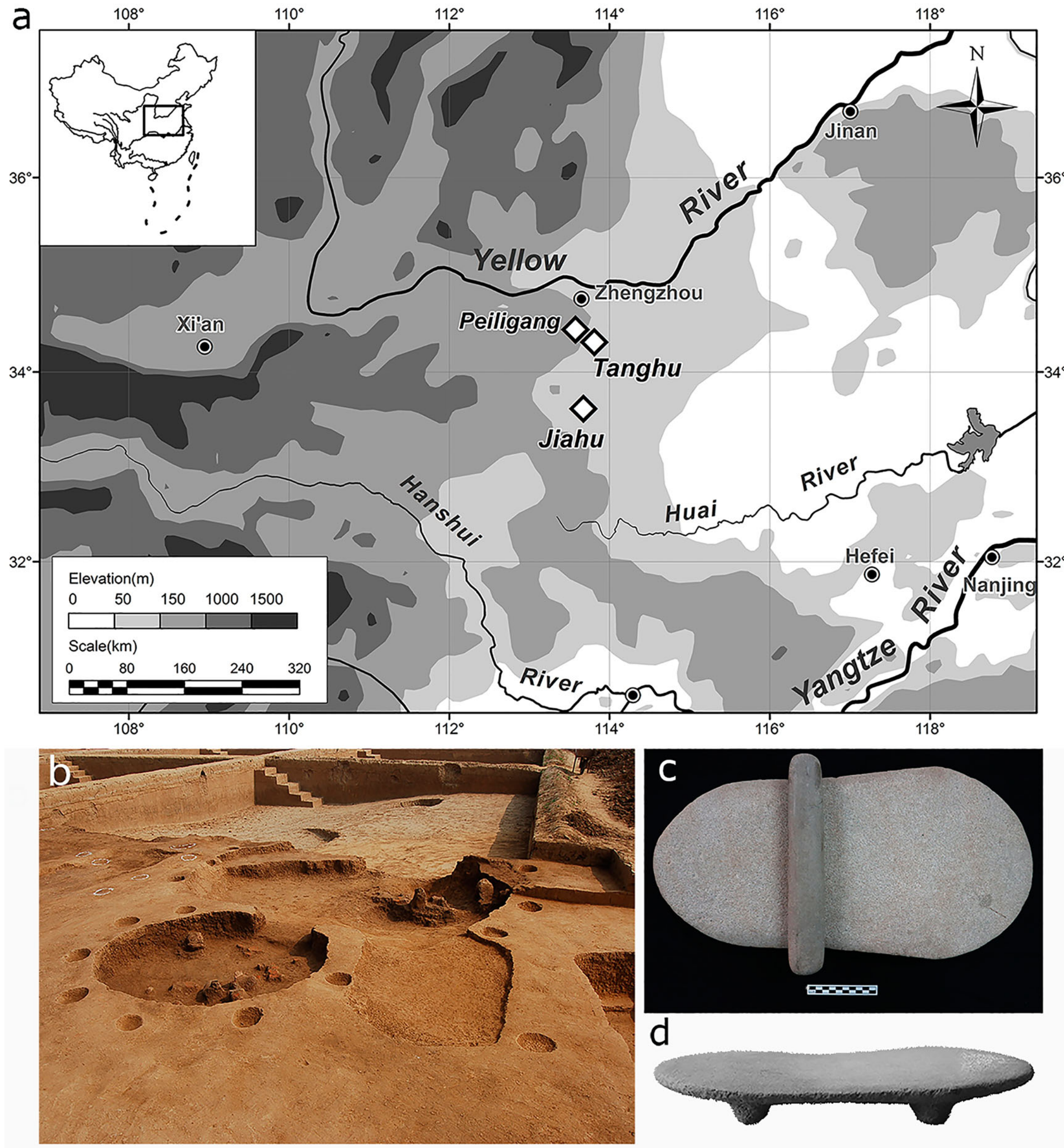

Figure 1. (a) the location of the sites of Tanghu, Jiahu, and Peilgiang in the upper catchment of the Huai River, China; (b) the house remains unearthed at the site of Tanghu; (c and d) the front and side views of a pair of grinding tools from the site of Jiahu in the research region, showing the symmetric shape and standing feet at the bottom of the slab.

and represents the largest Peiligang Culture settlement yet discovered in this region. A total of 63 semi-subterranean round houses (Figure 1(b)) and 201 pits have been excavated (Kaifeng, 1978; Xin et al., 2010; Zhang et al., 2008). Material remains including ground stone tools, pottery sherds, and animal bones were commonly found, while macrobotanic remains are poorly preserved at the site. Phytolith analysis of the soil samples has provided important evidence for the exploitation of cereals, suggesting that mixed farming of rice (*Oryza sativa)* and broomcorn millet (*Panicum miliaceum*) had started there by at least 5800 BC (Zhang et al., 2012).

The grinding tool assemblage from the site of Tanghu

The grinding tools from the site of Tanghu were made of sandstone characterized by medium grain size. This raw material can be found at the riverbeds seven kilometers to the north of the site (Dr. Jianxing Cui, personal communication). A similar type of material was also used for making grinding tools at neighboring sites, such as the site of Jiahu, Peiligang, Egou, and Shigu (Cui et al., 2017; Liu et al., 2010).

The morphology of the grinding tools was variable. The grinding slabs were divided into three types: (a) slabs with feet, with oval-shaped distal end; (b) slabs without feet, with an oval-shaped distal end, and (c) slabs without feet, with a triangular-shaped distal end (Zhang et al., 2008). The rollers were also divided into three different types based on the shape of the cross-section: round, triangular, and ovate. The grinding slabs range in size from 50 to 74 cm in length and 22 to 37 cm in width. The rollers range from 19.2 to 57.5 cm in length and 4.4–5 cm in diameter (Li, 1979). These typo-morphological features occur consistently in the grinding tool assemblages from the other nearby sites associated with the Peiligang Culture (Li, 1979; Zhang, 1999). Traces of manufacture were often encountered on the surfaces of the grinding tools, indicating that percussive and grinding techniques were used to form these artefacts. Pecking traces were often encountered in the grinding area of the tools, probably resulted from maintenance that were carried out to make grinding surfaces rougher and more efficient after a certain time of use.

At the site of Tanghu and other Peiligang Culture sites, complete grinding tools mostly came from graves and a few from pits that may be related to ritual human sacrifice (Kaifeng, 1978; Xin et al., 2010; Yang et al., 2017; Zhang, 1999; Zhang et al., 2008). The distribution pattern suggests that these objects were deposited intentionally in funerary contexts before they were worn out or broken through regular use. In contrast, grinding tools unearthed from the residential areas were all broken. Each fragment at Tanghu possesses over three fractured surfaces on average (Table 1), suggesting they were more likely to be intentionally broken. These fragments were distributed randomly in the residential area, pending a further discussion of their context of use, such as where the grinding activities were conducted.

For the current study, we selected all of the 17 grinding tools excavated from the residential area during the last two excavation seasons (Table 1 and Figure 2). Fourteen of these tools derived from grinding slabs and three from grinding rollers. The morphology of the grinding slabs (e.g. with or without feet) was undetermined because of their high degree of fragmentation (Table 1).

Methods

Starch grain and microwear analysis can provide evidence for the function of grinding tools. For instance, by extracting the preserved plant residues on grinding tools, starch grain analysis has been used to identify the types of plant foods processed (e.g. Babot & Apella, 2003; Fullagar et al., 2008; Liu et al., 2014a; Piperno et al., 2000). Microwear analysis provides further insight in the type of materials processed on these tools, and can also be used to infer how the grinding processes were conducted (Dubreuil & Savage, 2014; Van Gijn, 2014). More recently, a microwear reference baseline has been built and applied to indicate the adopted ancient grinding techniques (Li et al., 2019). These two analytical methods, i.e. starch grain and microwear analyses, complement each other and are often integrated in artefact studies (e.g. Fullagar et al., 2006; Gibaja Bao & Ferreira Bicho, 2015; Liu et al., 2013a).

Eight of the selected grinding tools from the site of Tanghu were subjected to starch grain analysis and the data have been published in Chinese (Li, 2015; Yang et al., 2015). In the previous starch research, the residue samples were taken from the grinding tools using ultrasonic toothbrush. Each brush head was used only once. The contamination was tested by comparing the number of the yielded starch grains from the used and unused surfaces of the grinding tools. In total, 242 starch grains were yielded from the used surfaces and no starch grains were found in the control samples. The identification of the starch grains were conducted based on the modern starch grain reference collection at the University of Science and Technology of China (over 50 species) as well as the published starch data (Torrence & Barton, 2006; Wan et al., 2012, 2011; Wei et al., 2010; Yang et al., 2009; Yang & Perry, 2013).

In this paper, we first summarize the previous identifications of the starch grains (Table 2) and then analyse these data using a quantitative approach. First, the identified plants were divided into three major categories: acorns, cereals, and USOs. Then the quantity and ubiquity value of each type of starch grains are calculated and compared. Ubiquity refers to the occurrence of identified plant taxa amongst the entire artefact sample spectra (Hubbard, 1980). The measurement of ubiquity has increasingly been applied in recent starch research (e.g. Ciofalo et al., 2019; Yao et al., 2016). Results obtained by combing the ubiquity value with the absolute number of different types of starch grain shed light on which group of plants were mainly processed on the grinding tools.

In addition, the grinding tools were subjected to microwear analysis, the results of which were integrated with the results from starch grain analysis. First, all of the artefacts went through a cleaning procedure under running tap water. Then, the used surface of each artefact was determined based on unaided eye observations. Because the grinding tools could not be transported out of the Chinese museums for analysis, casts using Polyvinyl siloxane (PVS) were made at key areas of the tool surfaces. This PVS material can get impressions of the stone surfaces and has been widely used for the study of

Table 1. Processed materials on the grinding tools inferred by microwear analysis.

Tool no.	Tool type	*Context*	Completeness	Fractured surface	Processed material
H80*	grinding slab	pit	fragment	2	cereals and bone
F52*	grinding slab	house	fragment	6	cereals
T0314(3):1*	grinding roller	cultural layer	fragment	3	cereals
T0314(3):2*	grinding slab	cultural layer	fragment	6	cereals
H74*	grinding roller	house	fragment	2	cereals
T0113(3):1*	grinding slab	cultural layer	fragment	2	cereals
T0113(4):1*	grinding slab	cultural layer	fragment	6	cereals
T0313(3)*	grinding slab	cultural layer	fragment	3	cereals
H8	grinding slab	pit	fragment	8	no use-related traces
H10	grinding slab	pit	fragment	4	cereals
F65	grinding slab	house	fragment	3	cereals
F41:3	grinding slab	house	fragment	3	cereals
T0103(3):8	grinding slab	cultural layer	fragment	3	cereals
T0203:3	grinding roller	house	fragment	1	cereals
T0401(4)	grinding slab	cultural layer	fragment	3	cereals
T0203	grinding slab	cultural layer	fragment	3	cereals
F3	grinding slab	cultural layer	fragment	4	cereals

Note: Eight of the artefacts with * were subjected to starch grain analysis

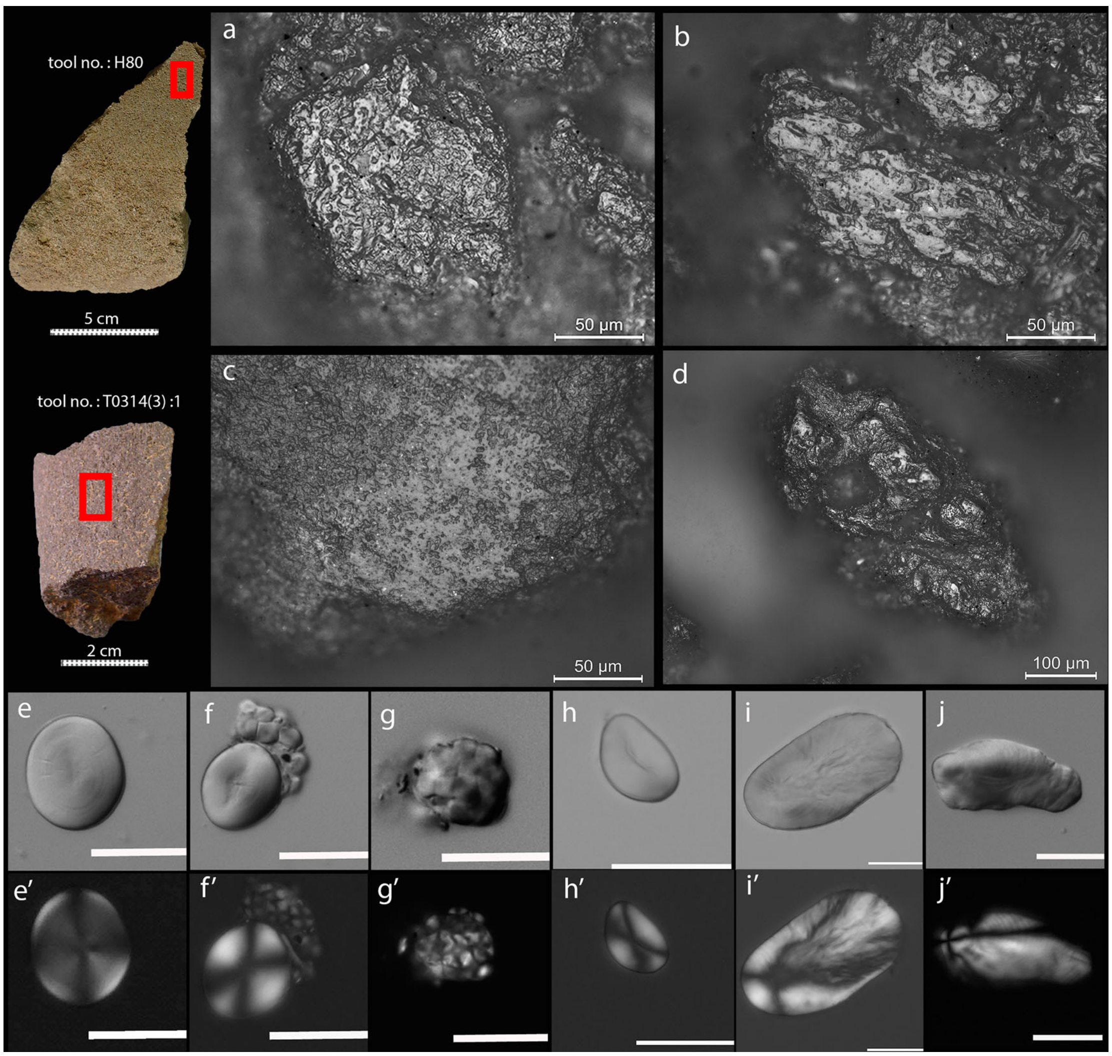

Figure 2. Microwear traces and starch grains on the grinding tools from Tanghu. (a) microwear traces associated with the dry-grinding of cereals, taken on the tool T0314(3):1(area with the red square); (b and c) microwear traces associated with processing bone, taken from used surface (area with the red square) of the tool H80; (d) microwear traces associated with the contact with hide, taken from the opposing surface of tool H80; (e and e′) starch grain from Triticeae tribe; (f and f′) starch grains from millet; (g and g′) starch grains from acorns; (h and h′) starch grains from rice; (i and i′) starch grains from unidentified USOs (scale bar of the starch grains: 20 μm, see the identification of the starch grains by Li, 2015; Yang et al., 2015).

Table 2. Starch grains identified on the grinding tools at the site of Tanghu.

Tool No.	Triticeae	*Setaria italica*	*Oryza sativa*	*Quercus* spp.	root of *Nelumbo nucifera*	Unidentified species from USOs
T0113(4):1*	3	1	0	0	5	0
T0113(3):1*	1	0	0	1	0	0
T0314(3):1*	47	91	0	3	6	0
T0314(3):2*	0	1	0	0	0	0
H80*	0	1	0	0	2	0
T0313(3)*	2	24	0	0	6	0
F52*	1	1	0	0	2	0
H74*	15	3	13	2	9	2
Total	69	122	13	6	30	2

grinding implements (e.g. Fullagar et al., 2017; Li et al., 2018; Liu et al., 2014b). Six of the grinding slabs had flat and smooth surfaces on two opposing surfaces. In such cases, samples were taken from both sides of the slabs. In total, 33 PVS cast samples were collected. The casts were analysed with a Leica DM 6000m metallographic microscope (under magnifications from 100x to 500x) equipped with a Leica DFC450 camera.

Observed microwear features included micro-striations (including their general distribution on the use faces), residues, and micro-polish. Micro-polish was studied in terms of its directionality, the degree of linkage, texture, morphology, reflectivity, and location on the micro-topography of the stone surface (see also descriptions by Adams et al., 2009; Van Gijn & Houkes, 2006; Van Gijn & Verbaas, 2007). Microwear features are described using a standardized terminology used in our previous publication (Li et al., 2019). The interpretations of the microwear traces are based on the microwear reference collections from the laboratory for Material Culture Studies at Leiden University (e.g. Figure 3(a–f)) as well as previous publications (Hayes et al., 2017; Li et al., 2018; Liu et al., 2010; Liu et al., 2014a; Van Gijn & Verbaas, 2009).

Results

Starch grain analysis reveals that grinding tools from the site of Tanghu were associated with processing various plant foods (Figure 2(e–j′) and Table 2), including grass seeds from Triticeae Tribes, foxtail millet (*Setaria italica*), rice, acorns (*Quercus* spp.), lotus root (root of *Nelumbo nucifera*), and some other undetermined USOs (Li, 2015; Yang et al., 2015). Further quantitative analysis of the starch data reveals that the grinding tools were used for mainly processing cereals, as the quantity and the ubiquity value of starch grains from cereals are both higher than those from USOs and acorns (Figure 4(a and b)). This result is consistent with the results of the microwear analysis, as all grinding tools apart from one (16 out of 17) show microwear traces resulting from processing cereals (Table 1). This type of microwear was characterized by a micropolish with a greasy, granular, and moderately reflective appearance (Figure 2(a)). It is worthy pointing out that grinding different types of cereals produce similar types of use-wear patterns (e.g. Figure 3(a and f)), so it is not yet possible to interpret the exact processed cereal based on use-wear traces. By comparing the microwear traces with the existing reference baseline used for inferring grinding techniques **(**Figure 3(a and b)**)**, it indicates that a dry-grinding technique (without soaking the processed cereals) was adopted for producing cereals at the site of Tanghu. At the nearby site of Jiahu, the same grinding technique was also employed for cereal processing (Li et al., 2019), possibly suggesting that this was a wider cultural choice.

Additionally, the microwear analysis suggests that the Tanghu inhabitants had placed a piece of hide or animal skin underneath the grinding slabs to facilitate the gathering of the processed cereals. This inference is based on the microwear traces observed on the un-used side of the grinding slabs (e.g. Figure 2(d)). This type of microwear traces resembles those related to hide processing, characterized by domed and smooth polish, which mainly formed on the higher micro-topography of the sampled stone surfaces (Figure 3(d)). The formation of this type of microwear traces was probably related to friction between the grinding tools with fallen plant material and the hide placed underneath. Similar microwear traces have been found on grinding tools at the Linear Bandkeramik (LBK) site of Geleen-Janskamperveld in the Netherlands (Van Gijn & Verbaas, 2009). A similar practice is observed in different present-day communities, where people gather flour by placing a cloth, plant leaves, or plastic bags underneath grinding tools (Peacock, 2013; Robitaille, 2016; Shoemaker et al., 2017).

Even though both analytical methods confirm that the grinding tool assemblage was closely associated with plant food processing, microwear traces resulting from bone processing were detected on the slab fragment H80 (Table 1). A smooth and reflective polish characterizes this type of microwear (Figure 3(c)). It has a pitted appearance and often displays troughs, and its morphology ranges from sinuous to domed (Figure 2(b and c)). Interestingly, the slab fragment H80 also

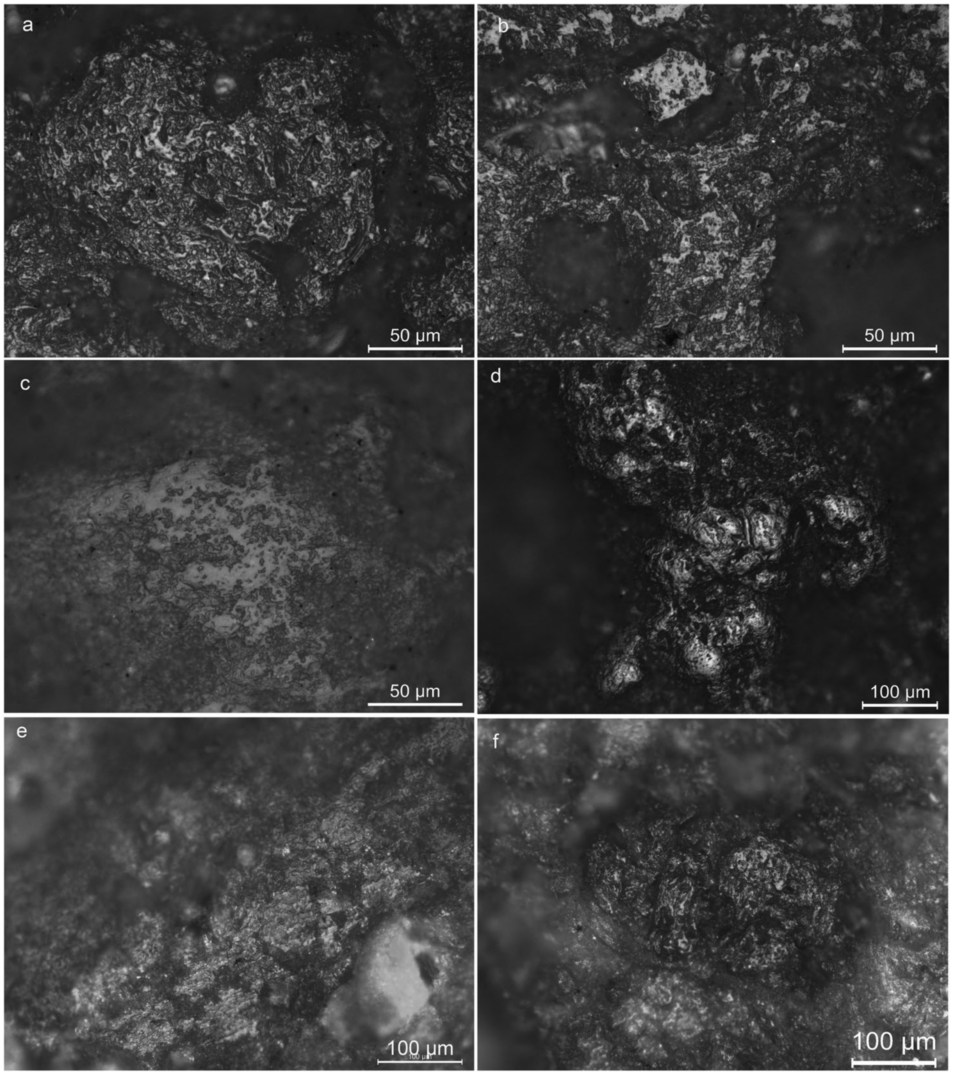

Figure 3. Microwear traces from the experimental grinding tools. (a) microwear traces resulting from grinding dry millet after 180 min; (b) microwear traces resulting from grinding soaked millet after 180 min; (c) microwear traces resulting from processing soaked bone after 180 min; (d) microwear traces resulting from rubbing deer skin after 180 min; (e) microwear traces resulting from processing acorns after 180 min; (f) microwear traces resulting from processing Einkorn wheat after 180 min. Note: The experimental grinding tools were sandstone cobbles collected from the valley of the Maas River in the southern Netherlands.

possesses microwear traces consistent with from the processing cereals (Table 1). In some cases, it is possible to infer the sequence of the formation of different types of microwear traces based on their distribution and development on the stone surface. However, the two types of microwear traces on the fragment H80 are located in different locations and do not overlap. Thus, it is not possible to determine which type of microwear traces developed earlier. Nevertheless, two types of microwear traces appearing on the same artefact indicates that this tool has a more complex life history than the other tools. It implies that this tool was probably multifunctional, as it could have been used for processing both bone and plant foods. Another possible interpretation is that this fragment was used as a plant processing tool initially, and then reused as an abrading tool to sharpen bone tools after it broke. Although bone artefacts have not been unearthed at the site of Tanghu so far, animal bones have been unearthed. In addition, bone needles, awls, and arrowheads were frequently encountered at other nearby sites associated with the Peiligang Culture (Ren et al., 1984; Yang et al., 2017; Zhang, 2015, 1999).

Discussions

Similar to the site of Jiahu (Li et al., 2019, 2018), our study reveals that cereals were the main processed plant foods and a dry grinding technique was preferred at the site of Tanghu. On the other hand, different choices of plant

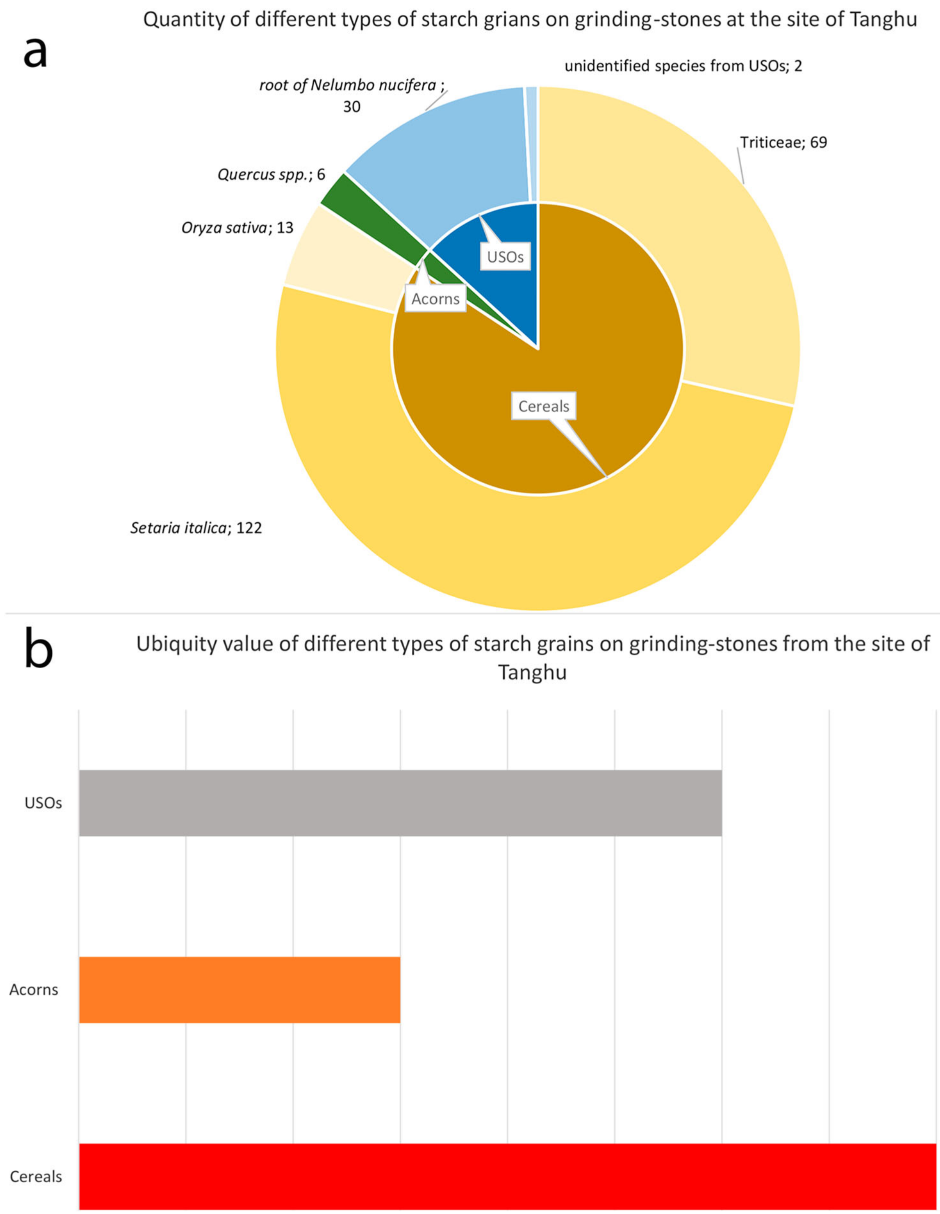

Figure 4. Comparison of the quantity (a) and ubiquity value (b) of starch grains from different types of plants at the site of Tanghu.

foods can also be detected among the Neolithic communities in the UCHR. For example, acorns were processed at sites of Tanghu, but not at the site of Jiahu; water plants and legumes were found on the Jiahu grinding tools, yet not on the grinding tools from Tanghu. Furthermore, at the sites of Egou, Shigu, and Peiligang in the same region, acorns were suggested to be the primary processed material on the grinding tools (Liu et al., 2010; Zhang et al., 2011). Similarities and differences in the plant food practices among different Peiligang Culture sites suggests that while cultural links between these communities are inferred through dietary and culinary practices, they also seem to possess their own distinctive characteristics. This proposition is further supported by other material traditions observed in this region. For instance, the sites of Tanghu and Jiahu show similarities in terms of their stone tool (e.g. grinding slabs with feet, stone sickles, and axes) and pottery assemblages (e.g. cooking vessels). However, fermented beverages (McGovern et al., 2004) and the earliest examples of Chinese inscriptions and tonal flutes (Li et al., 2003; Zhang et al., 2004, 1999) have been exclusively found at the site of Jiahu.

Apart from plant food processing, ethnographic and archaeological research worldwide indicates that grinding tools are involved in multiple daily tasks, such as processing of bone, antler, ivory, pigments, stone material, animal hide, clay, fibre and more (e.g. Adams, 1988; Dubreuil et al., 2019; Hamon & Le Gall, 2013; Hayes et al., 2018; Procopiou et al., 2011; Robitaille, 2016;

Rosenberg & Golani, 2012; Tsoraki, 2008, 2007; Tsoraki, Forthcoming). The presence of microwear traces associated with bone processing in the Tanghu grinding tool assemblage highlights that at least in some occasions these tools were multifunctional. At the nearby site of Jiahu, another different use of grinding tools was reported, where the grinding slabs with feet were mainly associated with processing wood-like material (Li et al., 2018). Notably, these different uses of the grinding tools from the Peiligang Culture sites were often overlooked in previous studies (e.g. Liu et al., 2010; Yang et al., 2015; Zhang, 2011). Research solely relying on starch grain analysis could easily neglect processed materials without starches. Microwear analysis also has difficulties in determining a multi-functional grinding tool when later developed microwear traces obliterate the previously formed ones on the stone surface. Furthermore, complete grinding tools are not always encountered in archaeological excavations, which means studies grinding tool fragments are hard to provide a thorough account of the function of grinding tools. Thus, as Hamon (2009) has pointed out, the multi-functional uses of grinding tools are very likely underrepresented in the archaeological record.

Conclusion

The results from the microwear and starch grain analysis show a strong correlation between plant processing and grinding tools from the site of Tanghu, which enable us to picture plant food production during the Neolithic period. Flours were produced from various plants, but mainly from cereals, which include both rice and foxtail millet. In addition, a dry-grinding technique was preferred for cereal processing. The neighboring sites shared similar food processing practices, but also exercised different choices toward plant foods.

Nevertheless, as Gokee and Logan (2014) have argued that food and craft activities could not be separated; one of the reasons is because tools were shared between different tasks. Apart from food processing, different uses of the grinding tools were detected at sites of Tanghu and Jiahu in the same region (Li et al., 2018), where some of the tools were associated with processing bone and wood-like material. These unique findings highlight that grinding tools were not only central for the study of ancient culinary practices but also hold the potential to reveal different household activities such as craft production.

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Weiya Li, Yuzhang Yang, and Yingjun Xin designed the research and took all the use-wear samples. The observation of the use-wear analysis was conducted by Weiya Li and checked by both Annelou van Gijn and Christina Tsoraki. The initial paper was written by Weiya Li, all the other co-authors worked on it by giving comments and editing.

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